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Renewable and Sustainable Energy Reviews 13 (2009) 696–702

RENEWABLE & SUSTAINABLE ENERGY REVIEWS

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Land use change sector contribution to the carbon historical emissions and the sustainability—Case study of the Brazilian Legal Amazon

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Received 13 September 2007; accepted 8 October 2007

Abstract

The paper presents 5 methodological aspects for the historic land use change accountability to compare 2 databases: the Historical Database on the Global Environment of RIVM, National Institute of Public Health and the Environment, adapted by the IVIG, International Virtual Institute of Global Change of the Federal University of Rio de Janeiro, named HYDE/IVIG and the Brazilian National Institute of Spatial Research database, named INPE database. The 5 aspects here considered are geographic limits; scale; basic methodology; deforestation concept; vegetal classification. It also presents their importance for the results of the calculus of deforested areas in the Brazilian Legal Amazon case. The use of the 2 databases information for carbon emissions calculation showed to be useful in terms of magnitude but not for qualitative analysis. The calculus of deforested areas is approximately similar for the period analyzed. According to HYDE/IVIG, the Brazilian Legal Amazon land use changes representing agriculture and pasture lands, account 422,070 km^2, between 1750 and 1990 and the natural areas modified were originally classified as 3 types: tropical forest, wooded tropical forest and savanna. According to INPE, the cumulative Brazilian Legal Amazon deforestation until 1990 accounts 415,000 km^2 and the natural areas modified were originally classified as 9 types. It means that different carbon contents by unit of deforestation have to be taken into account for the carbon emissions calculus. These numbers show the compatibility of the databases in terms of magnitude but the quality of the information present huge differences.

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Keywords: Land use change; Deforestation; Sustainability; Carbon historical emissions; Methodological comparison

Contents

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doi:10.1016/j.rser.2007.10.008

1. Introduction

The IPCC Inventory Manual for GHG emissions [1] presents a list of the most important gases by sectors to the contribution to climate change. The basic principle of the inventory methodology is that emission is a product of the activity level per emission factor. Some emission factors data are given globally or by regions but there is incentive to improve these data by countries and by activities sectors. The land use, land use change and forestry [2] sector involves the major uncertainties in terms of methodology for both activity level and emission factor. Therefore it is important to deeper evaluate the databases available to improve the methodologies for deforestation accountability and consequently for the carbon emissions inventories related to the land use change sector.

It is estimated the world cumulative emission of around 138 million Gg C due to land use change sector [3] and this number can vary a lot mainly because of different methodological assumptions. Two databases were compared for the calculation of the world historical CO2 emissions related to the land use change sector. These 2 databases are named here as INPE database [4], of the Brazilian National Institute of Spatial Research and HYDE/IVIG database, the Historical Database on the Global Environment of RIVM, National Institute of Public Health and the Environment [5], adapted by the IVIG (International Virtual Institute of Global Change of the Federal University of Rio de Janeiro) to present more detailed results by country and by regions inside countries. The INPE database contains information of the Brazilian deforestation process through satellite monitoring and HYDE/IVIG database contains not only land use data but also population, GDP, domestic animals, and energy consumption data. For the present work it was used only data of population, land use and domestic livestock.

For the comparison we used the world cartographic base called ESRI to estimate the historical deforested areas by country. The analysis of the data was made with basis on vast bibliographic research to verify if the land use data of HYDE/IVIG are adequate for the carbon emission calculation of the Brazilian case study. It was used vegetal typology data according to IBAMA [6] and the Amazon deforested data from INPE for year 1990 [4] to evaluate the Amazon case. Although INPE presents more recent data in its site, the year of 1990 was used for comparison because HYDE had not Land Use data for after 1990.

The CO_2 emission for a defined land use change can be calculated as follows

$$E_{CO_2}(c,0) = 0$$

$$E_{CO_2}(c,y) = 10^{-3}\left(\frac{44}{12}\right)\left\{\sum_b 10^2[A(c,y-1,b) - A(c,y,b)]D(b)\right\}$$

where $E_{CO_2}(c,y)$ is the emission of CO_2 (10^9 g CO_2/year) for a country (c) and year (y). $A(c, y, b)$ is the area (in km^2) of the biome b in country c in year y. $D(b)$ is the Density of carbon (in tons of carbon/hectare) of biome b.

2. Amazon case study

The Brazilian Legal Amazon case study was used as a parameter to compare the databases of land use change. It was used the information of INPE – National Institute for Spatial Research – compared with the information of the HYDE/IVIG methodology about land use change for mapping the Brazilian Amazon for the 2 databases and the 2 maps were overlapped to our analysis. The HYDE/IVIG database adopted the following land use classification proposed by HYDE (Table 1):

The following emissions factors [7] were adopted by the HYDE/IVIG database (Table 2):

After the comparison of the HYDE/IVIG and INPE databases, it was concluded that although they are not compatible in terms of localization of the deforested lands presented by the images, they are compatible in magnitude of the total deforestation area. According to INPE, the Brazilian Legal Amazon cumulative deforestation in 1990 was 415,000 km^2. According to HYDE/IVIG, the Brazilian Amazon deforestation in areas of croplands and grazing lands were around 422,070 km^2, from 1750 and 1990. The Figs. 1 and 2 presents the land use of Latin America in 1750 and in 1990, respectively and it can be seen that the land use changes during this period of 240 years occurred mainly over the Brazilian tropical forest, tropical woodland forest and savanna, according to the vegetal classification considered.

The following aspects were deeper analyzed to acquire a more detailed comparison between the HYDE/IVIG and INPE databases:

- geographic limits;
- scale;
- basic methodology;
- deforestation concept;
- vegetal classification.

Table 1
HYDE/IVIG land use classification

Cropland
Grazing land
Ice
Tundra
Wooded tundra
Boreal forest
Cool conifer forest
Temperate forest
Temp. deciduous forest
Warm mixed forest
Grassland/Steppe
Hot desert
Scrubland
Savanna
Tropical woodland
Tropical forest

Obs.: The HYDE vegetal classification was compared with Brazilian terminology by consultancy of Dr. Luiz Carlos Sérvulo Aquino, Forest Engineer of the Brazilian Ministry of Environment (8 and 9 July 2004).

Table 2
Carbon density factor above ground by biomes considered by HYDE/IVIG database

Biomes	Carbon density factor above ground by biome (tC/ha)
Cropland	5
Grazing land	5
Ice	0
Tundra	6
Wooded Tundra	7
Boreal Forest	64
Cool conifer forest	81
Temp. mixed forest	106
Temp. deciduous forest	117
Warm mixed forest	69
Grassland/Steppe	7
Hot desert	2
Scrubland	18
Savanna	29
Tropical woodland forest	80
Tropical forest	147

Source: Campos, Muylaert, and Rosa, Science of the Total Environment, 2005.

3. Geographic limits

The comparison of geographic limits of the 2 databases (INPE and HYDE/IVIG), shows differences related to territorial delimitation and consequently there are differences for calculation of deforested areas (Table 3).

The illustration below presents the geographic limits in curved lines from the INPE database over the strait lines of the square pixels of HYDE data for the land use map. It shows discrepancy between the areas established by the 2 different types of lines (Fig. 3). The border line definition for political division results in different calculus of the areas.

This problem was solved by the use of the themes intersection of the geographic limits base from the software Arc View 3.2a over the HYDE base. Therefore the off border areas were discharged and reconfigured and this new data is named HYDE/IVIG database.

4. Scale

The detailing levels of analysis vary according to the adopted scales. The land use monitoring project PRODES Digital, carried out by INPE, detects the Amazon deforestation through a database with very high details acquiring 6.25 ha as the unit of a minimum area or 0.0625 km^2, corresponding to a scale of 1:250,000. The HYDE database utilizes another very much smaller scale of 1:10,000,000, with the unit of minimum area equivalent to around 2500 km^2. The Fig. 4 shows the ranges of the scales used by the HYDE and INPE, respectively.

We can observe that HYDE data has area unit almost as big as Luxembourg area. Then, the adoption of different scales for the maps results in very different numbers for the land use change processes not only in terms of the deforested area calculation but also in terms of the biomes distribution which affects the correspondent carbon emissions factors.

Although INPE has a more adequate scale, the lack of charts for certain specific areas points out a problem of a lack of information. Besides, the definition of the polygons that cover the deforested areas is also a difficult issue to be tackled involving necessary great approximations (Fig. 5).

5. Basic methodology

The source of INPE and HYDE data are based in different principles. The main methodological difference is related to the type of data to acquire the same result—the deforested area as output. INPE has based in a monitoring system of the deforested of vegetal formations in Legal Amazon through the satellite images of the LANDSAT TM 5/7, with range of 215 images,

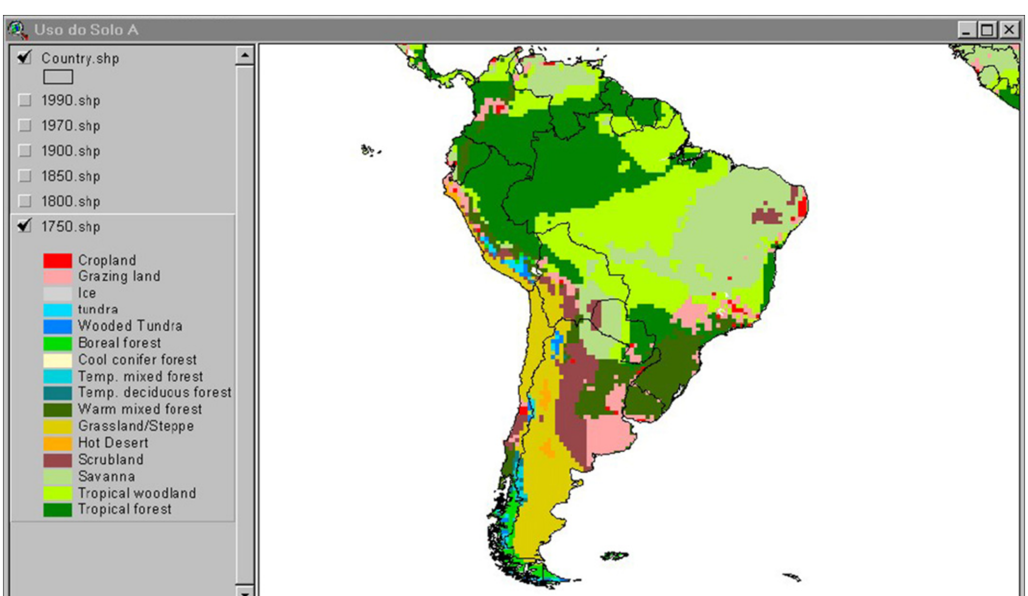


Fig. 1. Land use in Latin America in 1750. Source: HYDE/IVIG.

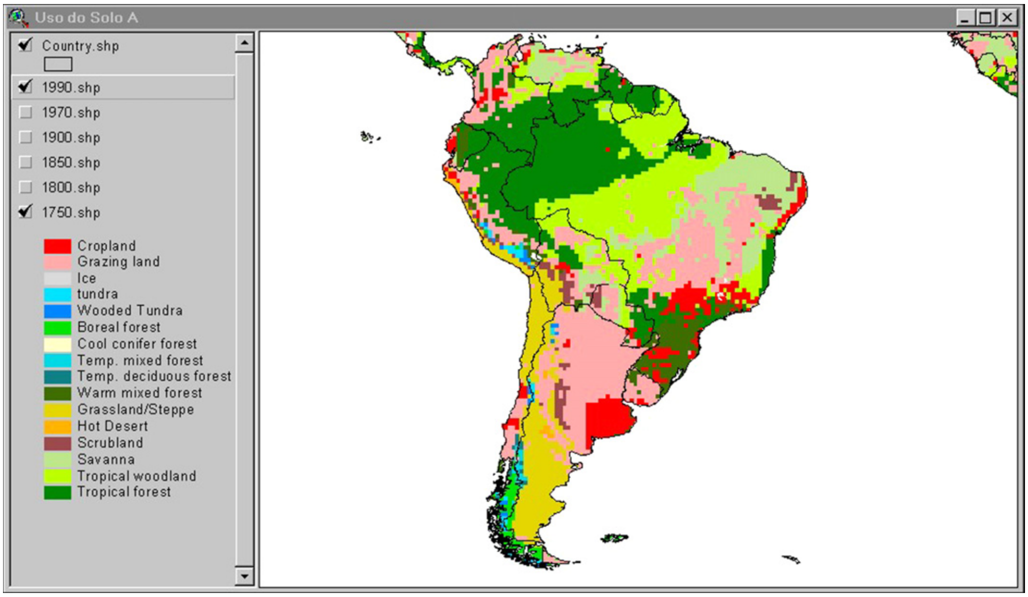


Fig. 2. Land use in Latin America in 1990. Source: HYDE/IVIG.

being 50 of these images in critical areas, corresponding to 82% of gross deforestation in 2002. This number increased to 75 scenes (images) in 2003, corresponding to 92% of the gross deforestation (Fig. 6). The methodology of HYDE is not based in satellite images; it is completely different, based on population data. From the population, some correlations are made to establish several indicators such as food and energy consumption until the calculus of the deforested areas. (Table 4).

6. Deforestation concept

There are different concepts of deforestation. The definition of deforestation for INPE accounts wood exploration areas, natural fires and activities of silviculture. The methodology of HYDE/IVIG does not consider the natural fires as deforested land if these areas grow again and do not change their use of land. It means that unless these areas will be transformed in another kind of activity, they still continue to be classified as forest even they are reforested with different characteristics. Besides, the methodology of HYDE/IVIG does not consider the areas used for silviculture activities as a deforested land, although this does not represent relatively a huge area in terms of size. Thus, the quantitative and the qualitative differences between the databases can be partly explained by this use of different concepts of deforestation (Tables 5 and 6).

The images overlapped (Fig. 7) illustrates the differences between the databases in the deforested areas. The polygons in red and pink refer to HYDE/IVIG database (agriculture and pasture, respectively) in 1990, and the black polygons represent

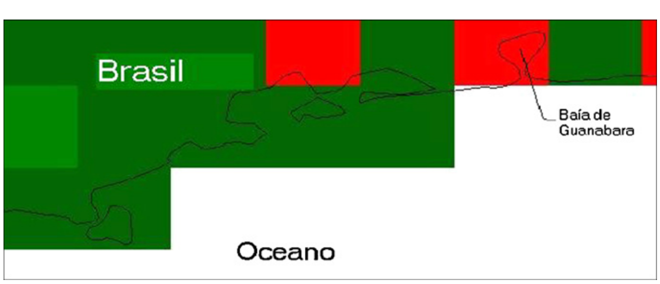


Fig. 3. HYDE limits in strait lines and INPE limits in curve lines show the partial overlap of land and ocean.

Table 3
Geographic limits—comparison of INPE and HYDE databases

INPE	Geographic limit established by curve lines
HYDE	Geographic limits are established in continental scale by strait lines. The vegetal biomes classification, the grazing land and the croplands were considered for the world as a whole. The countries geopolitical frontiers are not defined

Source: INPE and HYDE/IVIG.

Table 4
Basic methodologies—INPE and HYDE databases

HYDE	Monitoring made from Landsat satellite Images—215 scenes visually interpreted through remote sensors. From that, it is given the limits of the primary native forest and other types of non-forest coverage, identifying deforested areas. The loss of forested areas is considered from the data picked up by the satellite images
HYDE	The historical population density of the world is geographically located. The population density is associated to elements of natural vegetation, agriculture and pasture patterns. The losses of areas are considered as a function of population density and territorial uses

Deforestation taxes

Years	Number of scenes	Loss of forest area (km^2)
2000–2001	50	13,747
2001–2002	50	19,279
2002–2003	75	21,852

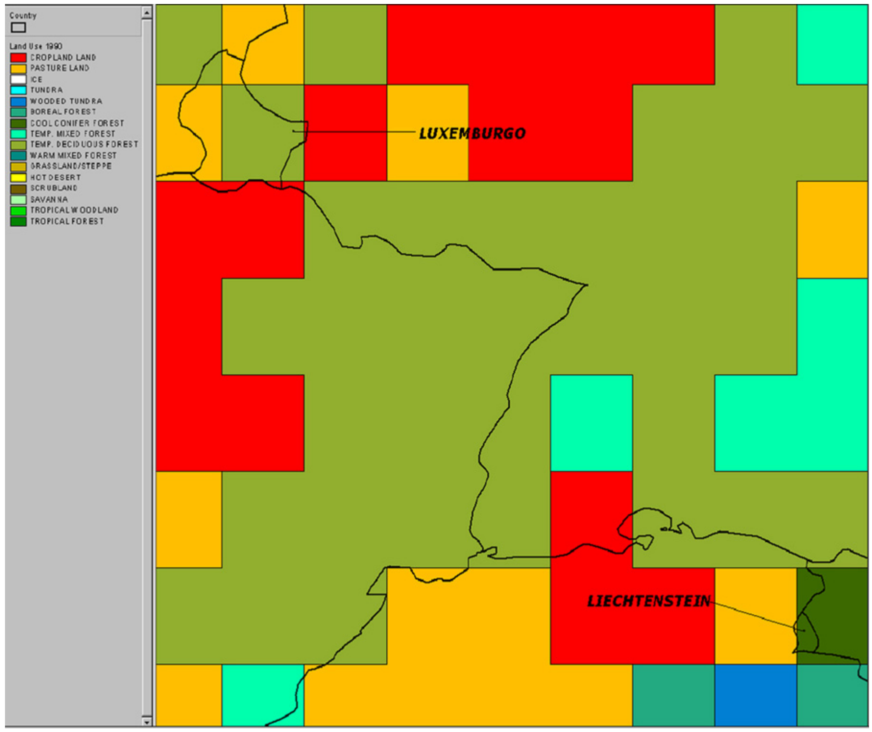


Fig. 4. Illustration of precise and range of the HYDE database scale with pixels of 2500 km^2.

the deforested considered areas according to the INPE for year 1997.

7. Vegetal classification

There are differences related to the vegetal classification for the 2 databases that results in different carbon emission factors for the same area of study. Considering the area of Legal Amazon, the criteria of HYDE for the biome Amazon accounts 3 vegetal classifications. That is because the HYDE original database involves the global as a whole what resulted in necessary approximations to take into account all existent

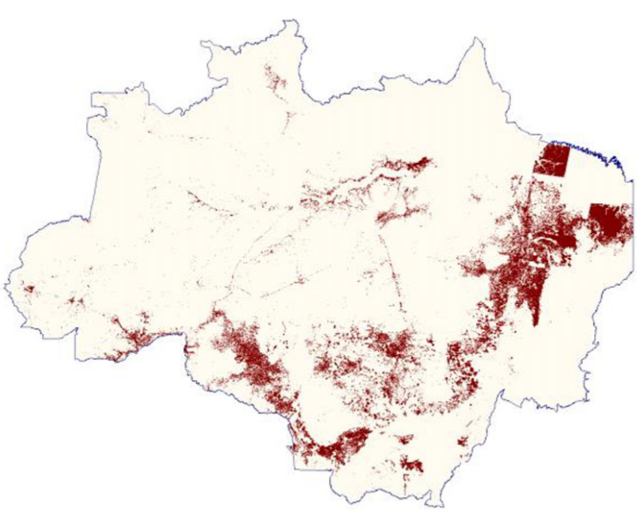


Fig. 5. Illustration of the precision of INPE database, 1997.

Table 5
Definitions of deforestation—INPE and HYDE

INPE	HYDE/IVIG
Deforestation–conversion of areas with primary forest physiognomy by anthropogenic actions to the development of agro-pasture and silviculture activities. This definition also includes areas in process of secondary succession and areas under forest decomposition	Deforestation–generalization made from the population density data and the increasing demand for land use expansion on forest areas to the development of agro-pasture activities, demand for wood to siderurgy, and charcoal, mining and navy industries

Table 6
Actions that result deforestation according to INPE e HYDE/IVIG

Deforestation primary forest physiognomy changes	INPE (deforestation concept based on the analysis of the forest cover change)	HYDE/IVIG (deforestation concept based on the analysis of land use change)
Agriculture activities	Yes	Yes
Pasture activities	Yes	Yes
Silviculture activities	Yes	No
Secondary sucession process	Yes	No
Forest recomposition	Yes	No
Forest cover affected by wood exploration	No	No
Forest cover affected by natural fires	No	No

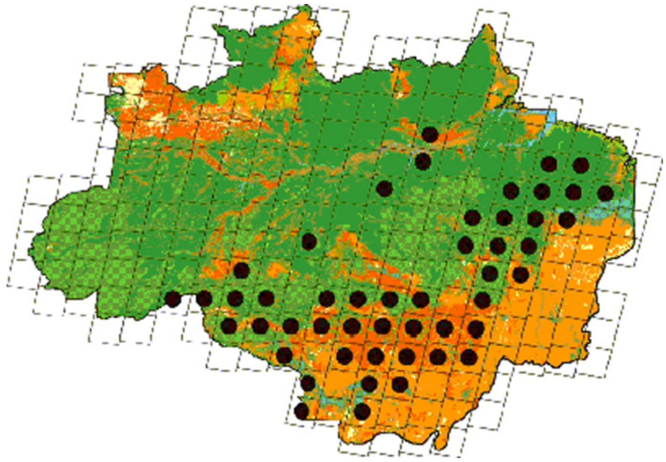


Fig. 6. Prodes digital for Legal Amazon. Environment satellite monitoring. Fifty of two hundred and fifteen images in critical areas, corresponding to 82% of gross deforestation in 2002.

Table 7
Classification of Vegetal formations according to INPE and HYDE

INPE	HYDE
Pioneer formations areas	Savanna
Ecologic tension areas	Wooded Tropical forest
'Campinarana'	Tropical forest
Hydro areas	
Stationary forests	
Dense forests	
Ecologic refuge	
Savanna	
Estepe Savanna	

biomes in the world. According to the criteria of INPE/IBAMA, the Amazon biome accounts 9 classes of vegetation or land uses, like the following scheme (Table 7).

8. Conclusion

It was made a study of the data from different Brazilian institutions to compare 2 land use change databases. The methodology used by INPE to characterize the land use was compared with the methodology of the HYDE/IVIG database for the case of the Brazilian Legal Amazon.

After the analysis of the following 5 items – geographic limits, scale, basic methodology, deforestation concept and vegetal classification – it can be concluded that the principal differences between the HYDE and INPE databases are related to the basic methodology and to the concept of deforestation.

The HYDE methodology is based in the correlation between population density and activities that cause land use change and INPE data is based on satellite images. The concepts of deforestation can represent different calculus of deforested areas due to the accountability of areas that are re growing as they were deforested areas. For HYDE the deforested areas are only the ones that really changed their land uses definitely (as the agriculture and pasture areas) but this is not the same for INPE. Nevertheless these differences are mostly qualitative for the Brazilian Legal Amazon case here studied. The differences of vegetal classification indicate that the calculus of carbon emissions can be quite different for the same area. It depends on the vegetal classification adopted because the carbon content can differ a lot.

According to HYDE, the Brazilian Legal Amazon land use changes representing agriculture and pasture lands account

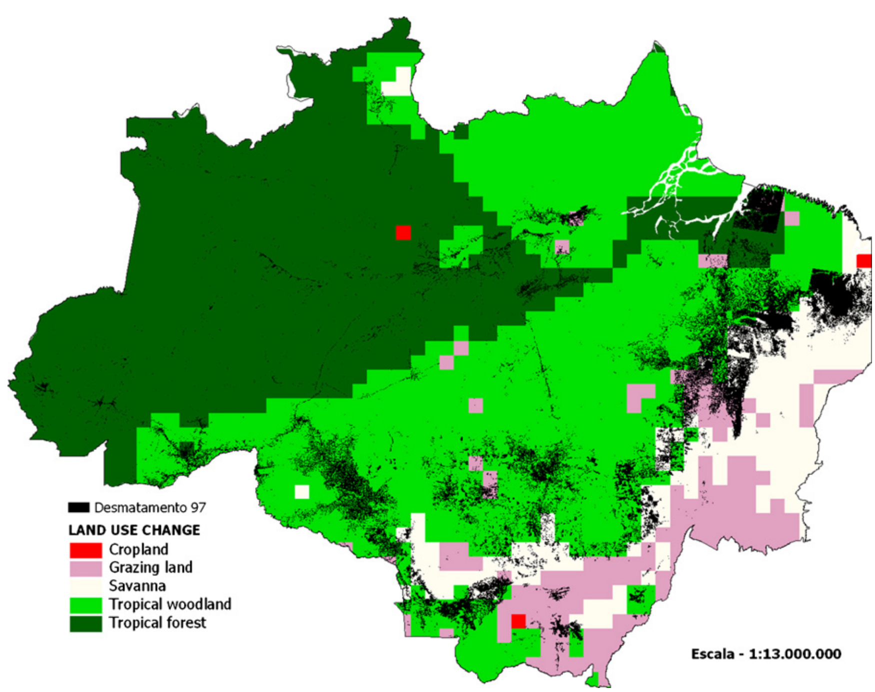


Fig. 7. Overlap of deforested areas for INPE (in black) and for HYDE/IVIG (agriculture and pasture areas in red and pink). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

422,070 km^2, between 1750 and 1990. The natural areas were originally tropical forest, wooded tropical forest and savanna. According to INPE, the cumulative Brazilian Legal Amazon deforestation until 1990 was 415,000 km^2. These numbers show the compatibility of the 2 databases in terms of magnitude (big numbers) but the quality of the information present huge differences. These differences indicate that it is important to adopt a more detailed focus of analysis with new indicators such as deforestation area by State or by Region or by sector, not subject of analysis in the present study.

Acknowledgements

Eletrobrás, RIVM, Brazilian Institute of Aero spatial Research and Brazilian Ministry of Science and Technology are gratefully acknowledged.

References

[1] IPCC, revised 1996 IPCC guidelines for national greenhouse gas inventories: reference manual (vol. 3), 1996.
[2] Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ, editors. IPCC, special report: land use, land-use change, and forestry. A special report of the IPCC. Cambrige University Press; 2000.
[3] Muylaert de Araujo MS, de Campos CP, Rosa LP. GHG historical contribution by sectors, sustainable development and equity. Renew Sust Energy Rev 2007;11(4):988–97.
[4] INPE, monitoring of Brazilian Amazon forest by satellite 1998–1999. National Institute of Spatial Research:; 2000/2004, www.inpe.gov.br.
[5] RIVM, historical land use changes over the past 300 years: new global data sets. 2001. Available in CD-ROM.
[6] IBAMA, database ''Poesia''. 2001: Centro de Sensoriamento Remoto (CSR-IBAMA).
[7] de Campos CP, Muylaert MS, Rosa LP. Historical CO2 emission and concentrations due to land use change of croplands and pastures by country. Sci Total Environ 2005;346:149–55.